

# AN OBJECTIVE METHOD FOR ESTIMATING INVERSION HEIGHTS ABOVE SAN DIEGO BASED ON RADAR MEASUREMENTS

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## ABSTRACT

Two-way frequency distributions were constructed of 266 temperature-inversion heights and 36 no-inversion cases versus each of two radar-determined indicators of anomalous propagation. Inversion conditions were derived from San Diego radiosonde data. The radar used was the WSR-57 (10 cm.) at Santa Catalina Island. The frequency distributions were utilized as contingency ratios. These ratios and their products were then used to construct tables of most likely inversion heights (or no-inversion) for all combinations of class intervals of radar data. The distribution of significant contingency ratios is in fair agreement with theory for this particular configuration of transmitter, targets, and inversion characteristics. A test of this method of predicting inversion heights showed it to be better than persistence only when secondary high contingency ratios as well as the largest ratios were employed.

## 1. INTRODUCTION

The data presented in this report are a portion of those gathered by the Catalina WSR-57 AP/Angel Project. This study is intended to test the feasibility of operationally utilizing observations of anomalous propagation (AP), radar angels, and sea clutter to estimate inversion conditions over coastal southern California. While many operational procedures have been developed to estimate or forecast propagation conditions by use of meteorological data, this is one of the few times that the reverse approach has been attempted [1]. Data were gathered during most of 1964 and 1965. However, modifications in the data collection procedure precluded use of the entire 2-yr. sample. About 8 months of data (late August 1964 to mid-April 1965) were used in this study as the sample, and about 4 months (August through mid-December 1965) were used for verification.

## 2. DATA

At radiosonde release times, radar measurements of range to ground targets and/or signal strengths of selected targets were taken along or near the azimuths to the five upper-air stations in coastal southern California: Point Arguello, Point Mugu, San Nicolas Island, Santa Monica, and San Diego. The radar measurements, which should be related to propagation conditions and, hence, to inversion characteristics, were then compiled in conjunction with radiosonde inversion data. Only inversions based below 5,000 ft. were analyzed. Because the radar data from the San Diego bearing showed the greatest variability and seemed to be highly dependent upon inversion conditions, these data were selected for investigation. Cases of

multiple inversions were not included in this report,\* nor were data concerning angels and sea clutter.

In order to simplify the analysis, this study is limited to correlation of only one inversion parameter, the height of the base,\*\* with radar propagation. Also, Kerr [2] has observed that the principal variation, with time, in the structure of inversions over the southern California coast is in the height of the base; and that this feature, rather than strength or thickness, is most easily correlated with transmission. An additional simplification is that no attempt was made to consider spatial variations in inversion height along the ray path.

Since the Catalina radar is at an elevation of 2,125 ft., it is often above the inversion base and below the top or, less frequently, above both the base and top. This further complicates the problem of trying to relate inversion heights to superstandard propagation. In order to resolve this difficulty, two radar indicators of superrefractive conditions were employed in establishing the relationships: (a) range to AP targets, or no occurrence of AP, along the azimuth to San Diego; (b) signal strength in decibels above a calibrated receiver sensitivity ( $-103$  decibels below 1 milliwatt (d.b.m.)) from a small island group, the Los Coronados, about 20 n. mi. south of San Diego and 83 n. mi. from the radar. When AP occurs along the San Diego azimuth, it is from mountainous terrain 2,000 to 6,000 ft. high at ranges greater than 114 n. mi. The elevation of the highest of the Los Coronados Islands

\*Multiple inversions occurred only 3 percent of the time over San Diego during this sampling period. However, this probably is not representative of their true frequency since they were noted in 15 percent of 370 cases of AP observations taken prior to this sample.

\*\*For reasons explained later, one category of inversion height considers tops also.

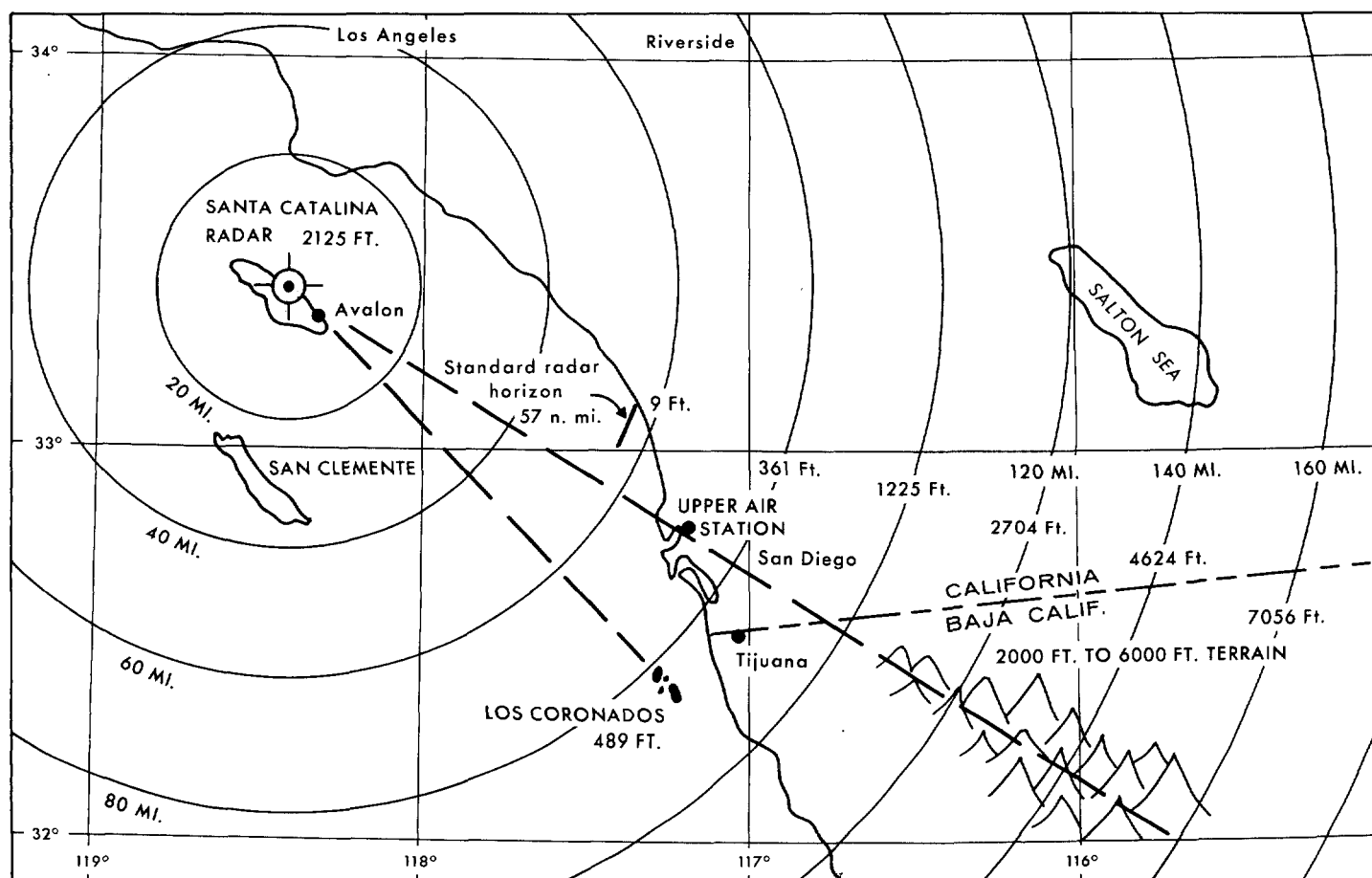


FIGURE 1.—Map showing locations of radar, targets, and upper air station used in this report. Numbers on range circles are height in feet of the top of the earth's shadow at that range under standard propagation conditions.

is 489 ft. m.s.l. Figure 1 shows the locations of the radar, targets, and upper-air station.

Indicator (a), range to the AP targets, the mountainous terrain, was noted to be greatest under conditions of elevated inversions that enveloped and extended above the radar, or were based slightly above the transmitter. Indicator (b), the signal from the shallow islands, appeared to be strongest when the inversion base was near sea level, while higher-based inversions seemed to have little or no effect.

The island group proved to be a good indicator of anomalous propagation because the highest point is just about at the top of the earth shadow [3] under standard conditions for this range to target and height of transmitter. Figure 1 shows the height of the top of the earth shadow for various ranges under standard conditions. Observation of the radarscope during periods of standard refraction confirm that the islands are barely visible at such times. Similarly, the mountainous terrain (2,000 to 6,000 ft.) in indicator (a) is in the theoretical earth shadow region under standard conditions because the mountains' elevation generally increases with range from the radar and the top of the earth's shadow increases from about 2,500 ft. at 114 n. mi. to 7,000 ft. at 160 n. mi., the farthest

that AP is observed along this azimuth. Again, this is confirmed in practice since these mountains do not appear during periods of standard refraction.

The measurements of range to ground targets and signal strength (db.) were taken at one-half degree tilt angle and the islands were scanned in azimuth for maximum signal to avoid errors caused by slight variations in indicator readout. Determination of signal strength was accomplished by standard WSR-57 precision attenuators and R-scope.

### 3. ANALYSIS OF DATA

Figure 2 is a frequency distribution of inversion heights and no-inversion cases for the 302 observations included in this report. Since the sample period covered only about 8 months, it is by no means representative of the actual distribution of inversions above San Diego. Note that inversion bases occurring below 1,500 ft. are separated into two classes—those with top above 1,500 ft. and those with top below this level. This was necessary because of the 2,125-ft. elevation of the radar. Results of this distinction can be seen in table 1, a two-way frequency distribution of inversion heights versus range to ground targets, which

shows that AP (ground targets detected at ranges of 115 n. mi. or more) occurred only 2 of 56 times (4 percent) when the top was below 1,500 ft. and 18 of 103 times (17 percent) when the inversion top was above this level. Also, note that AP occurred only when an inversion was present. However, the reverse statement cannot be made since inversions occurred most often with no anomalous propagation indicated by this parameter.

### RANGE TO GROUND TARGETS

As mentioned previously, AP targets are likely to appear under conditions of an elevated inversion. Table 1A substantiates this since AP (range to ground targets 115 n. mi. or more) occurred only twice when the inversion top was below 1,500 ft. and 66 times when it was above this height. Further, the highest frequencies of occurrence of AP are confined to the categories: top above 1,500, base below 1,500, and base 1,500 to 2,499 ft. Thus, for all the cases involving tops above 1,500 ft., only 15 of 66 observations (23 percent) of AP were with inversion bases well above the radar, i.e., above 2,500 ft. If "well above the radar" is considered as above 3,500 ft., only 6 of 66 cases (9 percent) of AP involved inversions well above the radar. Elevated inversions are almost always associated with AP beyond 145 n. mi., i.e., 34 of 36 cases (94 percent) involved inversions based above 1,500 ft.

The contingency ratios in table 1C were computed by a procedure outlined by Panofsky and Brier [4]. These ratios are quotients of the values in the relation (table 1A) and no-relation (chance) (table 1B) contingency tables. For instance, the contingency ratio of 2.0 in column 2, row 4 of table 1C implies that an inversion with base between 1,500 and 2,499 ft. is twice as likely as chance to occur when the range to ground targets is between 115 and 145 n. mi. Assumptions of independence of successive observations are necessary before statements concerning the significance of these ratios can be made. However, Kerr [2] has stated that the most variable parameter of southern California marine inversions is height. See Kerr's [2] figure 4.25, p. 332, for a depiction of time versus height of inversion base.

The contingency ratios in table 1C reflect what was concluded above, particularly the general increase in

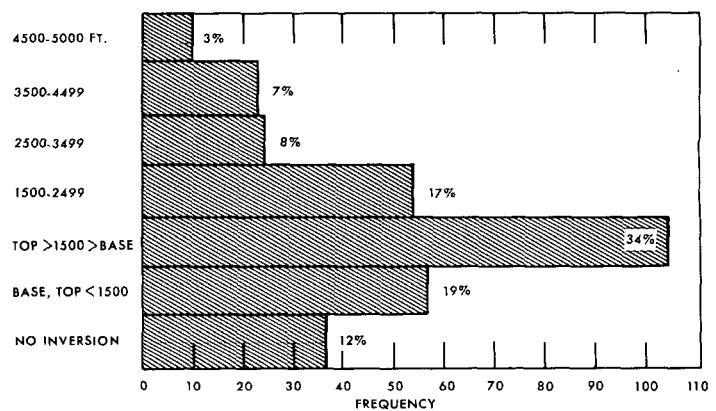


FIGURE 2.—Frequency distribution of inversion heights and no inversion for the 302 cases included as the sample.

height of inversion categories with the largest ratios as the range to ground targets increases. The uniformly low ratios in the no-AP column (range less than 115 n. mi.) are to be expected since inversions occurred most often with no AP indicated. However, it is noteworthy that the highest ratios for the no-AP category occurred in conjunction with the categories of no-inversion and both base and top below 1,500 ft.

An explanation for the observed distribution (and resulting contingency ratios) is that elevated inversions are of the type more likely to extend any superrefractive properties some distance inland than would low-level or surface-based inversions. Also, Kerr [2], referring to an experiment conducted in this area in 1944 and 1945, concluded that superrefractive type inversions much above the radar resulted in barely detectable signal levels (wavelength 55 cm.), whereas the lower superstandard layers caused the signal to increase markedly. (See Kerr's [2] fig. 4.25, p. 332.) However, lower superstandard layers for the Catalina radar (elevation 2,125 ft.) are of the elevated type which also are able to penetrate inland as explained above. Hence, the combination of Catalina's elevated transmitter and elevated superrefractive layers, at or slightly above the radar, provides the most favorable configuration for enhancement of superstandard propagation to inland terrain.

TABLE 1.—Distribution statistics on inversion height vs. range to ground target

Inversion height (ft.)	A. Observed distribution, inversion height vs. range to ground target				B. Expected distribution, inversion height vs. range to ground target				C. Contingency ratios derived from parts A and B		
	Range (n. mi.)				Range (n. mi.)				Range (n. mi.)		
	<115	115-145	>145	Total	<115	115-145	>145	Total	<115	115-145	>145
4,500-5,000	8	0	1	9	7	1	1	9	1.1	0	1.0
3,500-4,499	17	0	5	22	17	2	3	22	1.0	0	1.7
2,500-3,499	14	2	7	23	18	2	3	23	0.8	1.0	2.3
1,500-2,499	20	12	21	53	41	6	6	53	0.5	2.0	3.5
Top >1,500 >Base	85	17	1	103	80	11	12	103	1.1	1.5	0.1
Base, Top <1,500	54	1	1	56	43	6	7	56	1.3	0.2	0.1
None	36	0	0	36	28	4	4	36	1.3	0	0
Total	234	32	36	302	234	32	36	302			

TABLE 2.—*Distribution statistics on inversion height vs. signal strength*

Inversion height (ft.)	A. Observed distribution, inversion height vs. signal strength				B. Expected distribution, inversion height vs. signal strength				C. Contingency ratios derived from parts A and B		
	Signal strength (db.)				Signal strength (db.)				Signal strength (db.)		
	<26	26-39	>39	Total	<26	26-39	>39	Total	<26	26-39	>39
4,500-5,000.....	8	0	1	9	5	3	1	9	1.6	0	1.0
3,500-4,499.....	20	2	0	22	13	8	1	22	1.5	0.3	0
2,500-3,499.....	22	1	0	23	13	9	1	23	1.7	0.1	0
1,500-2,499.....	33	19	1	53	30	19	4	53	1.1	1.0	0.3
Top >1,500 > Base.....	37	52	14	103	59	38	6	103	0.6	1.4	2.3
Base, Top <1,500.....	27	28	1	56	32	21	3	56	0.8	1.3	0.3
None.....	26	9	1	36	21	13	2	36	1.2	0.7	0.5
Total.....	173	111	18	302	173	111	18	302			

### SIGNAL STRENGTH FROM LOS CORONADOS ISLANDS

Tables 2A, B, and C are relation, no-relation, and contingency ratio tables for the second indicator of superrefractive propagation—signal strength (db.) above a calibrated receiver sensitivity ( $-103$  d.b.m.) from the Los Coronados Islands. The distribution in table 4 suggests that inversions based below 1,500 ft. are more likely to result in strong signal levels (above 26 db.) than are those above this height. Of 159 cases of inversions based below 1,500 ft., 95 (60 percent) were associated with a signal stronger than or equal to 26 db., versus only 24 of 107 (22 percent) when the inversion was based 1,500 ft. or higher. A distinction between the lower two categories of inversion—base and top both below 1,500 ft. and base below, top above 1,500 ft.—for signal strength greater than 39 db. is also noted. Fourteen of 103 cases (14 percent) when the inversion top was above 1,500 ft. involved signal strength of 40 db. or stronger, versus only 1 of 56 (2 percent) when the inversion was entirely below 1,500 ft.

The contingency ratios in table 2C reflect the relationships noted above. For the weakest category of signal strength, the largest contingency ratios involve either no inversion or inversions based above 1,500 ft., whereas the ratios for inversions based below 1,500 ft. are both less than unity. A distinction between the two lower categories of inversion height can again be noted. These ratios are about equal (1.4 and 1.3) for 26 to 39 db., but the one for base below, top above 1,500 ft. is much larger (2.3 vs. 0.3) at 40 db. or stronger.

The distribution of signal strength versus inversion height supports the conjecture expressed earlier that lower-based inversions seem to enhance superstandard propagation to the shallow island group. This can best be explained by again considering the configuration of radar and target with respect to inversion height. Those inversions based above 1,500 ft., while perhaps greatly influencing radar propagation, would in some cases trap the radar energy in an elevated duct, thus preventing it from reaching the shallow islands. Inversions based below

1,500 ft. apparently are able at times to bend the beam over the radar horizon at low levels, thus enhancing signal return from the islands. A further refinement of this may be seen for inversions with bases below, but tops above, 1,500 ft. This type inversion was the category most often associated with strong signal return from the islands—14 of 18 cases (78 percent) of signal strength above 39 db. were coincident with this type inversion. Fourteen percent of all inversions with base below, top above 1,500 ft. were associated with signal strength above 39 db.; compared to only 2 percent for inversions based 1,500 ft. or higher, and 2 percent for those with both base and top below 1,500 ft. Since an inversion with base below, top above 1,500 ft. could envelop both the radar and shallow island group, strong ducting of energy directly to the islands (including that in side lobes) would be possible.

### 4. APPLICATION

The tables of contingency ratios (tables 1C and 2C) could be used separately to give an estimate of inversion height, particularly if both show a high ratio of the inversion falling into one category. Since this is not always the case, the ratios were multiplied to yield a table of ratios for all combinations of anomalous propagation indicators. Independence of the two indicators is prerequisite to their significance when used together. Because one indicator is essentially a measure of superrefraction at high levels (range to mountainous terrain) and the other at low levels (signal strength from four shallow islands), some degree of independence between the two may be assumed.

The product contingency ratios are given in table 3. The category of inversion associated with the highest valued ratio for a given combination of the two propagation indicators provides an estimate of inversion conditions. These ratios are boxed in heavy outline. Secondary high ratios are printed in italics. The final estimate should involve other information in connection with the radar method.

TABLE 3.—Product contingency ratios computed from tables 1c and 2c.

Estimate of inversion height (ft.)	Range to ground targets (n. mi)								
	<115			115-145			>145		
	Signal strength (db.)			Signal strength (db.)			Signal strength (db.)		
	<26	26-39	>39	<26	26-39	>39	<26	26-39	>39
4,500-5,000.....	1.8	0	1.1	0	0	0	1.6	0	1.0
3,500-4,499.....	1.5	0.3	0	0	0	0	2.6	0.5	0
2,500-3,499.....	1.4	0.1	0	1.7	0.1	0	3.9	0.2	0
1,500-2,499.....	0.6	0.5	0.2	2.2	2.0	0.6	3.9	3.5	1.1
Top >1,500 > Base.....	0.7	1.5	2.5	0.9	2.1	3.5	0.1	0.1	0.2
Base, Top <1,500.....	1.0	1.7	0.4	0.2	0.3	0.1	0.1	0.1	0
None.....	1.6	0.9	0.7	0	0	0	0	0	0

## 5. VERIFICATION

Tables 4, 5, and 6 are estimated versus observed inversion conditions for the 181 cases used for verification. Table 4 gives the verification when only the highest valued contingency ratios from table 3 are utilized. The results are poor with only 46 correct estimates out of 181 cases (25 percent). It was stated previously that inversions most often occur with no indication of anomalous propagation by increased range to ground targets. An analogous statement is also true for inversion occurrence and weak signal strength from the islands. This accounts for much of the poor result when this method is applied since the first column of table 1C—no indication of AP—has its highest ratio for inversions based between 4,500 and 5,000 ft. Because inversions at this level occur very infrequently (3 percent for the sample data), a disproportionate number (73 of 181 or 40 percent) were estimated when applying the radar method based solely on largest contingency ratios. Also, in many cases there is no significant difference between contingency ratios for a given combination of AP indicators, viz, columns 1, 2, 5, and 7 in table 3 each has at least two ratios that are nearly equal. Thus, if an estimate of inversion height is based solely on a ratio that is only slightly larger than others in its category, the significance of the estimate is greatly reduced. This is noted in column 2, where only a slightly larger ratio (1.7) for inversions entirely below 1,500 ft. than that for inversions with base below and top above 1,500 ft. (1.5) was computed. The result of this slight difference in ratios is seen in verification (table 4) where many inversions (38) that were estimated to be entirely below 1,500 ft. verified in the category of base below, top above 1,500 ft.

Table 5 shows that persistence (the inversion condition measured by radiosonde 12 hr. ago used as estimate of the current situation) verified much better than the radar method based solely on highest contingency ratio—98 of 181 cases or 54 percent verified correctly, versus only 25 percent for the radar method.

TABLE 4.—Verification table based only on largest contingency ratios

Observed inversion height (ft.)	Estimated inversion height (ft.)							Total
	4,500-5,000	3,500-4,499	2,500-3,499	1,500-2,499	Top >1,500 > Base	Base, Top <1,500	None	
4,500-5,000.....	2	1	0	0	0	0	0	3
3,500-4,499.....	3	0	1	1	0	0	0	5
2,500-3,499.....	2	0	6	4	0	0	0	12
1,500-2,499.....	6	0	0	18	9	2	0	35
Top >1,500 > Base.....	35	0	0	5	13	38	0	91
Base, Top <1,500.....	10	0	0	0	0	7	0	17
None.....	15	0	0	1	0	2	0	18
Total.....	73	1	7	29	22	49	0	181

TABLE 5.—Persistence verification table

Observed inversion height (ft.)	Estimated inversion height (ft.)							Total
	4,500-5,000	3,500-4,499	2,500-3,499	1,500-2,499	Top >1,500 > Base	Base, Top <1,500	None	
4,500-5,000.....	0	0	1	0	1	0	1	3
3,500-4,499.....	0	2	1	1	0	0	1	5
2,500-3,499.....	0	2	2	4	2	0	2	12
1,500-2,499.....	0	0	3	19	11	2	0	35
Top >1,500 > Base.....	0	0	2	10	69	8	2	91
Base, Top <1,500.....	0	1	0	2	7	1	6	17
None.....	1	1	1	0	4	6	5	18
Total.....	1	6	10	36	94	17	17	181

TABLE 6.—Verification table based on largest and secondary contingency ratios

Observed inversion height (ft.)	Estimated inversion height (ft.)							Total
	4,500-5,000	3,500-4,499	2,500-3,499	1,500-2,499	Top >1,500 > Base	Base, Top <1,500	None	
4,500-5,000.....	2	0	1	0	0	0	0	3
3,500-4,499.....	0	4	0	1	0	0	0	5
2,500-3,499.....	0	0	11	1	0	0	0	12
1,500-2,499.....	5	0	1	23	4	2	0	35
Top >1,500 > Base.....	30	0	0	5	56	0	0	91
Base, Top <1,500.....	10	0	0	0	0	7	0	17
None.....	0	0	0	0	0	2	16	18
Total.....	47	4	13	30	60	11	16	181

Therefore, use of the radar method based solely on largest contingency ratios is not justified since significantly better results are obtainable by persistence estimates.

A somewhat biased method of utilizing the contingency ratios for test verification improved the score of the radar method considerably. Both the largest and the secondary contingency ratios in table 3 were used in verification. Thus, if the radiosonde-measured inversion

condition verified for any of the significant ratios, a hit was scored. The number of hits was 119 out of a possible 181 or 66 percent, compared to only 25 percent for the radar method based solely on largest ratios, and 54 percent scored by persistence.

Skill scores utilizing persistence as a standard were computed. A skill score of 0.25 was achieved by the biased method involving both largest and secondary ratios versus a value of  $-0.63$  for the system employing only highest ratios.

## 6. CONCLUSIONS

The radar method for estimating inversion conditions demonstrated an improvement over persistence only when secondary contingency ratios were also utilized. While this is biased verification, an unbiased test could be expedited using the contingency ratios as a guide. This would involve real time estimates of inversion conditions using the radar method in conjunction with other available information, such as stratus and haze top reports and/or anticipated vertical stretching or contraction of the marine layer from synoptic or mesoscale influences. A possible application of the method would be in detecting changes in inversion conditions between times of upper-air soundings or in regions where soundings are not available. This could be of utility in forecasting temperature, humidity, stratus, and smog conditions for southern California. For instance, the fact that the radar was picking up ground targets at great distances inland could be an indication that the marine layer beneath the inversion had penetrated the interior, a very important, and usually difficult-to-forecast, change for fire weather and aviation applications.

These types of forecasting problems are more of a day-to-day task in this area than those related to precipitation. Application of the Catalina radar to non-precipitation related forecasting problems, such as relating sea clutter to Santa Ana winds [5], [6], for example, can greatly increase its effectiveness in this arid to semi-arid region.

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